Field-Scale Spatial Variability: Yield Response of Potatoes

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First Law of Geography

- All things are related, but nearby things are more related than distant things.

W.R. Tobler, 1970

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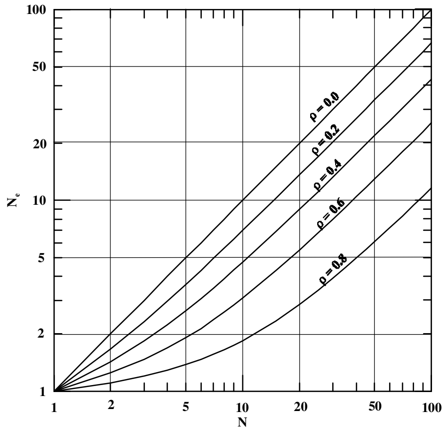
Effective number of observations

- The effective number of observations, N_e, is related to the number of observations, N, as a function of autocorrelation, ρ.
- A 50-year record with ρ=0.2 contains as much information as a 33-year record with ρ=0.0.



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Descriptive Statistics for Spatial Studies

- (auto)covariance function

$$C(h) = \mathrm{cov}[A_i(x), A_i(x+h)] = \frac{1}{N}\sum_{i=1}^{N-h}[A_i(x_i) - \bar{A}]\,[A_i(x_i+h) - \bar{A}]$$

- autocorrelation function

$$\rho(h) = \frac{\mathrm{cov}[A_i(x), A_i(x+h)]}{\sqrt{\mathrm{var}[A_i(x)]}\,\sqrt{\mathrm{var}[A_i(x+h)]}}$$

- variogram

$$\gamma(h) = \frac{1}{2N(h)}\sum_{i=1}^{N(h)}[A_i(x_i) - A_i(x_i+h)]^2$$

where

$A_i(x_i)$ = value of A_i measured at x_i

h = distance

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Descriptive Statistics for Spatial Studies

These statistics are commonly used in spatial studies. They indicate the degree that the data at any two points are related to each other and, thus, give some indication of non-independence of the data.

They are shown here as a function of distance, h, between any two points, and are omnidirectional. Directional bounds can be specified such that only data points within a specified radius will be considered.

These terms apply to univariate spatial studies. In multivariate spatial studies, the prefix "cross" is frequently used (i.e., cross variogram).

The variogram is a fundamental metric in geostatistics and is related to the other measures.

Developments and Issues

- Geostatistics exploits fundamental autocorrelation in data (Matheron, 1970; etc.)
- Issue: pseudoreplication (Hurlbert, 1984)
- Issue: information being lost by not experimenting and measuring as a landscape continuum (Peterson et al., 1993)
- Issue: computation intensity no longer an impediment; emphasis on design of spatially efficient experiments (Edmonson, 2005)

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Objectives

- Simulate a more realistic, gradually varied treatment design for potato response to nitrogen.
  - continuous
  - field-scale
- Correctly test for treatment effects in the presence of spatial variability.
- Describe the effect of field properties in yield response.

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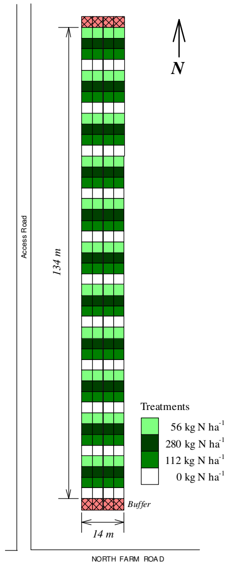
Experimental Field

- BARC-W, Maryland
- 0.18 ha (135 m x 14 m)
- Experimental unit: 3 m x 3 m
- Transect: 44 units
- Field: 4 transects
- Potatoes planted DOY 113
  (April 23, 2003; April 22, 2004)
- Planting density 3.6 plants m^{-2}
- Buffers
  - 3 m at N and S ends
  - 1 row along edges



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Experimental Field

- Calcium nitrate applied at 22 DAE (2003) and 17 DAE (2004)
- 4 levels
  - 0 kg N ha^{-1}
  - 112 kg N ha^{-1}
  - 280 kg N ha^{-1}
  - 56 kg N ha^{-1}
- Constant across field width
- Sinusoidal pattern along field length
- No irrigation
- Potatoes harvested 118 days after planting

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Experimental Field

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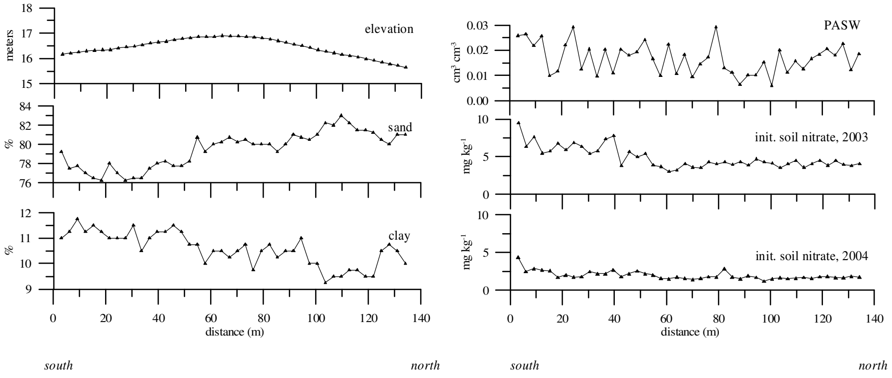
Experimental Field

Image of potato field taken in July, 2003.

There were no noticeable disease impacts, and pests and weeds were controlled throughout the 2003 and 2004 growing seasons.

A rye cover crop was planted in the field prior to both the 2003 and 2004 experiments. The rye was mechanically plowed under while the field was chiseled and disked during field preparation prior to planting.

Transects of Field Properties



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Transects of Field Properties

Because the field was long and narrow, data gathered over the field were averaged into a transect for analysis.

Field topography was sampled via a real-time kinematic GPS survey at an approximate spacing of 1 point per 2.7 meters.

A soil probe was used to extract a 15-cm sample of the surface soil from the center of each of the 176 plots for particle size analysis and to determine initial pre-application soil NO3-N.

Undisturbed soil cores (5.4 cm dia. x 6.0 cm len.) were collected from the center of each unit of one field transect (44 units) to determine plant available soil water capacity (PASW). PASW was determined as the difference between volumetric water contents at matric potentials of -0.01 MPa and -1.5 MPa.

Correlation of Field Properties

	Elev	Sand	Clay	PASW	InitN03	InitN04
Elev	1.00	-0.24	0.24	-0.10	-0.10	-0.02
Sand		1.00	-0.81**	-0.19	-0.65**	-0.44**
Clay			1.00	0.20	0.59**	0.54**
WHC				1.00	0.22	0.27
InitN03					1.00	0.73**
InitN04						1.00

**Significant at the 0.01 probability level.

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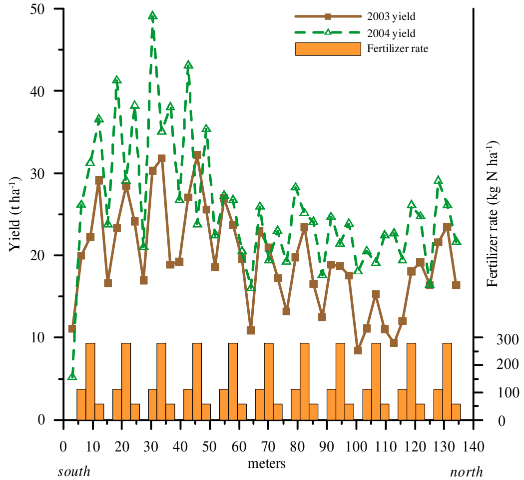
Transects of Yield



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Mixed Model Analysis

General linear mixed model

$$\mathbf{y} = \mathbf{x}\beta + \mathbf{Zu} + \mathbf{e}$$

$$Var(\mathbf{e}) = \mathbf{R}$$

Spatial definition of **R** (SAS)

$$Cov(e_i, e_j) = f\left(\sigma^2, h, \rho\right)$$

$$\sigma^2 = \sigma_p^2 + \sigma_n^2$$

σ^2 = variance; h = distance between e_i and e_j; ρ = range; σ_p^2 = partial sill; σ_n^2 = nugget

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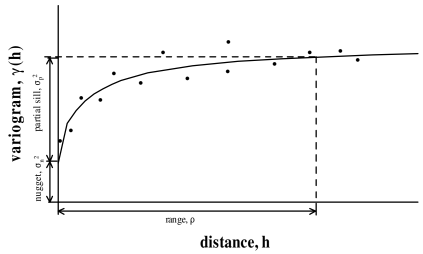
Mixed Model Analysis - 1

General Linear Mixed Model:

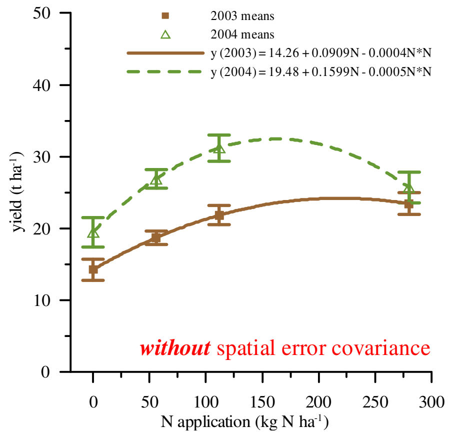
xβ = fixed effect(s)
Zu = random effect(s)
e = random errors

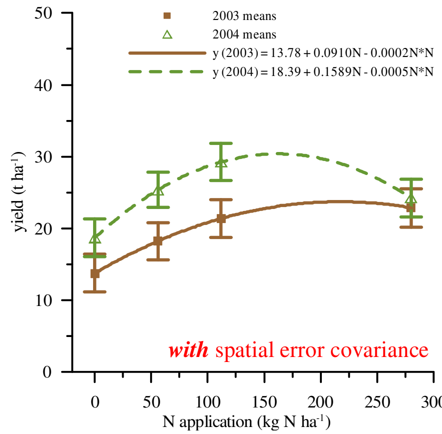
Since the data were effectively contiguous, no blocking was necessary and the random effects were not considered. The data for 2003 and 2004 could have been considered a random (year) effect, but two years of data does not allow for reasonable variance calculations.

In SAS, the components of the covariance matrix are output in terms of the variogram. But the data considered in the covariance are the <u>residuals</u> after the fixed effects have been taken into account.



Nitrogen Treatment Response – Means and Standard Errors

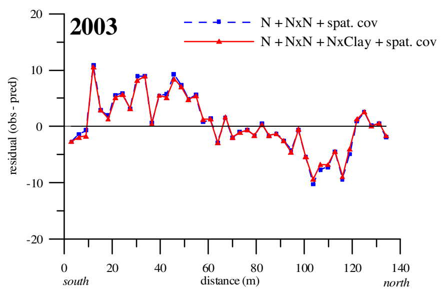


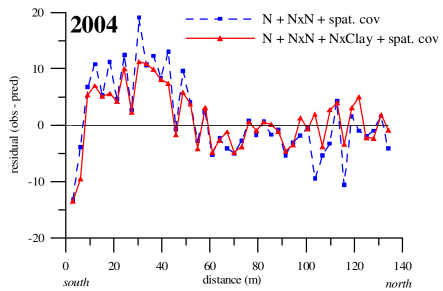


Mixed Model Analysis

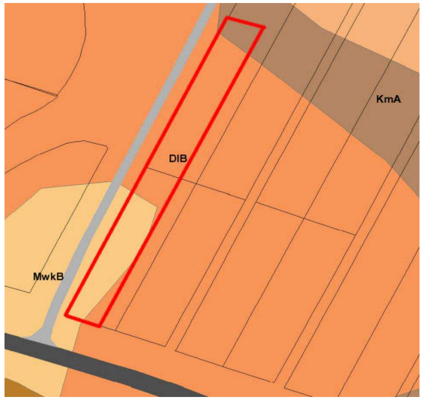
Model	Non-spatial R^2	Spatial R^2
2003		
N treat + N treat^2	0.34	0.68
N treat + N treat^2 + N treat x Clay	0.40	0.70
2004		
N treat + N treat^2	0.28	0.54
N treat + N treat^2 + N treat x Clay	0.59	0.69

Analysis of Residuals





Soil Type



- KmA
  Keyport and Matawan Soils,
  0 – 2% slopes
  sandy loam, silt loam
- D1B
  Downer-Ingleside Loamy
  Sands, 2 – 5% slopes
  loamy sand
- MwkB
  Matawan and Keyport Soils,
  2 – 5% slopes
  loamy sand, silt loam

Special Soil Report, 1995

Mixed Model Analysis

Model	Non-spatial R^2	Spatial R^2
2003		
N treat + N treat²	0.34	0.68
N treat + N treat² + N treat x Clay	0.40	0.70
N treat + N treat² + N treat x Soil Type	0.66	0.74
N treat + N treat² + N treat x Clay x Soil Type	0.67	0.74
2004		
N treat + N treat²	0.28	0.54
N treat + N treat² + N treat x Clay	0.59	0.69
N treat + N treat² + N treat x Soil Type	0.53	0.64
N treat + N treat² + N treat x Clay x Soil Type	0.63	0.71

Mixed Model Analysis - 2

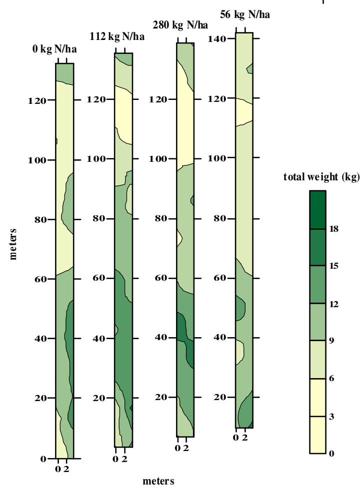
The coefficient of determination (R^2) was calculated for various mixed models developed for the data. The quadratic model (N treatments + N treatments²) was considered the base model—the nitrogen response curve. The only significant field variable (as determined by backward elimination regression analysis) was clay.

The yield residuals (observed yield – predicted yield) exhibit some spatial patterning. Including the N treatment x clay interaction decreases the residual variability, especially at the north end of the field in the 2004 data.

Other interactions (e.g., soil type—a classification variable) were tested although not developed through significance testing or AIC minimization.

Yield Estimation

- Interpolated yield estimates using kriging
- High yields at one end of field; low yields at other end
- Poor yield response to fertilizer where clay and init. soil nitrate low



Is there more?

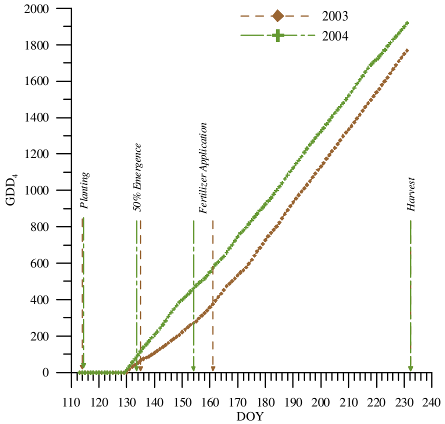
Weather Data for Growing Season

	Avg. Daily Temp. (ºC)	Total Precip. (mm)
2003	20.6	522
2004	21.8	509

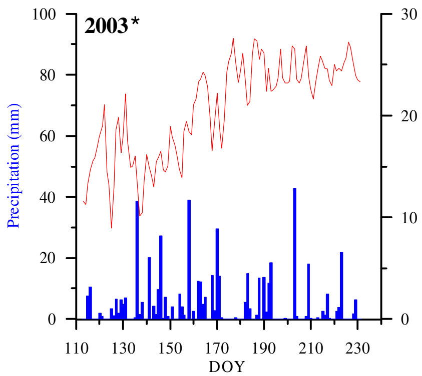
Growing Degree Days

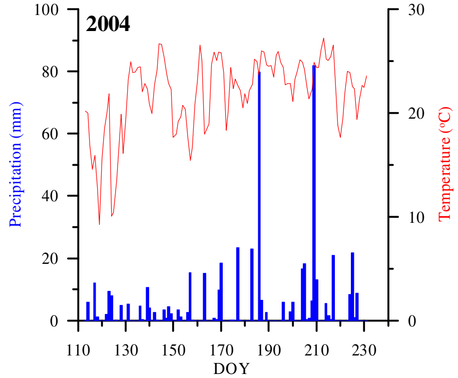
$$GDD = \sum_{i=1}^{n} (T_i - T_b), \quad i = 1,\ldots,n$$

T = avg. daily temp.
b = base temp. = 4℃



Growing Season Weather





*wettest year on record!

Summary and Conclusions - 1

- Field properties varied throughout field.
- Yield response varied throughout field.
- Yield response to treatments varied throughout field.
- Spatially correlated errors made treatment means less distinct.
- The linear association between yield and treatments increased if spatially correlated errors were considered.

Summary and Conclusions - 2

- The effect of field properties (continuous and classed) was tested; clay content and soil type class both proved significantly related to yield.
- Residuals still exhibited spatial variability throughout field.
- Pattern of yield response similar both years; magnitude of yield will require management and climatic inputs.
- Treatment application pattern allowed for systematic testing of all treatments throughout field, effectively increasing experimental design by four.

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